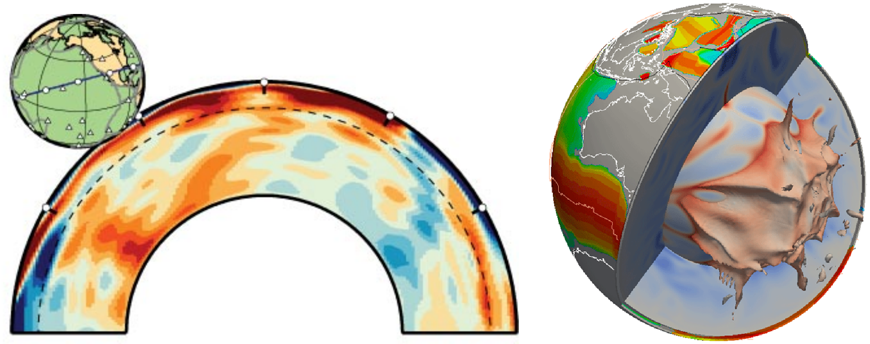
# 1D and 3D seismic models and interpretations

Thorne MS[1], Zhang Y[2], Ritsema J[2,*],
Evaluation of 1D and 3D seismic models of the Pacific lower mantle with S, SKS and SKKS traveltimes and amplitudes, *J. Geophys. Res.*, doi: 10.1002/jgrb.50054, 2013.

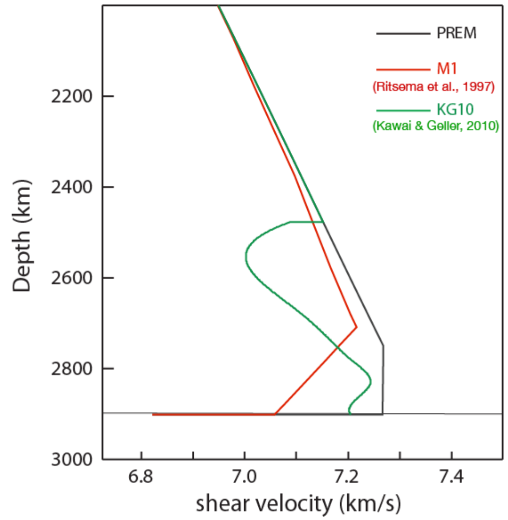

[1]University of Utah
[2]University of Michigan
[*]at European headquarters (09/12 -- 07/13)

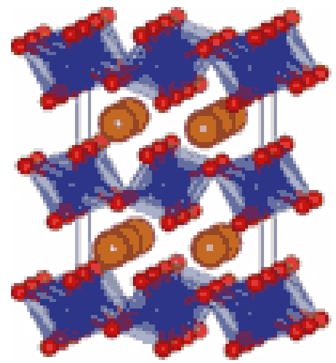
1. Travel-times and amplitudes
2. Small- and large-scale structure
3. Super blobs and D'' layering

# Multi-scale images and interpretations



M. Gurnis (www)



S. Matar (www)

Schuberth et al., 2009; Zaroli et al., 2010; Sheaffer and Lebedev, 2013

## Large-scale, mantle-wide seismic velocity heterogeneity

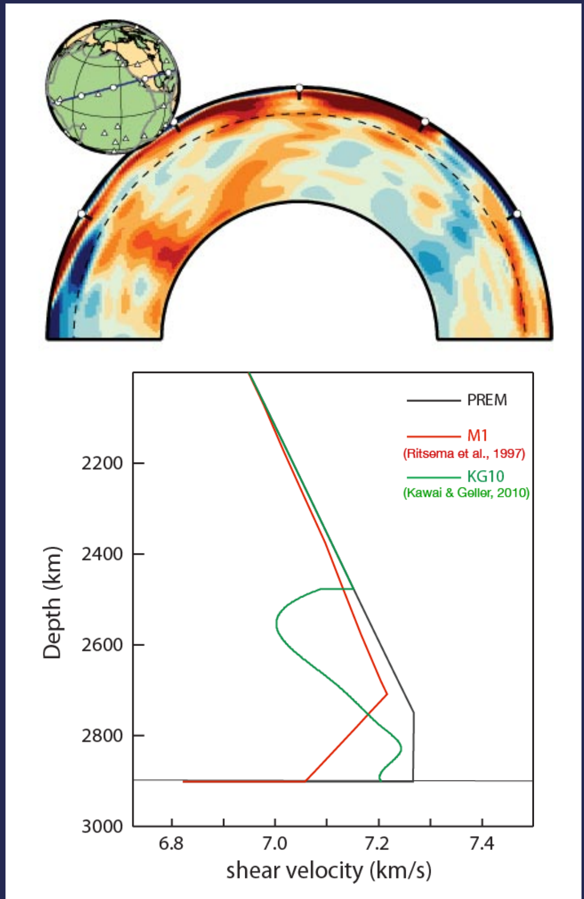
- Waveforms from global networks
- Large-scale (3D) parameterization
- ultra-low resolution

Lay et al., 2006; Kawai and Geller, 2010; Thorne et al., 2013; Cobden and Thomas, 2013

## Fine-scale layering of D”

- Waveforms from regional networks
- Local (1D) parameterization
- ultra-high resolution

# Tomography and 1D profiles




1. 3D and 1D representations of the same structure?
2. Are 3D blobs artificially stretched –
   Are 1D profiles artificially compressed?

Test this with regional seismic data (presumably global-scale 3D heterogeneity is not important)

# *Classical* tomography

Shear velocity variation of degree 40

*scale lengths > 1000-km*

Rayleigh wave dispersion

*fundamental mode and overtones*

Travel-times

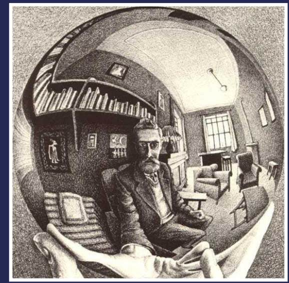
*$S, S_{diff}, SS, SSS, SS_M, SSS_M, SSSS_M,$*
*$ScS, ScS_2, ScS_3, SKS, SKKS$ (+ depth phases)*

Splitting functions

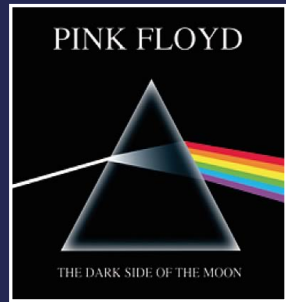
*< 3mHz (Arwen's talk later this morning)*

*Classical means:*
*rays (path integrals) – PREM – linearization –*
*crustal corrections – phases with names –*
*signal-to-noise ratio > 1*

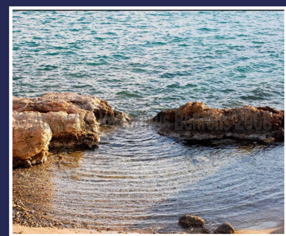
*reflections*



*refractions*




*diffractions*



# *Modern* waveform inversion

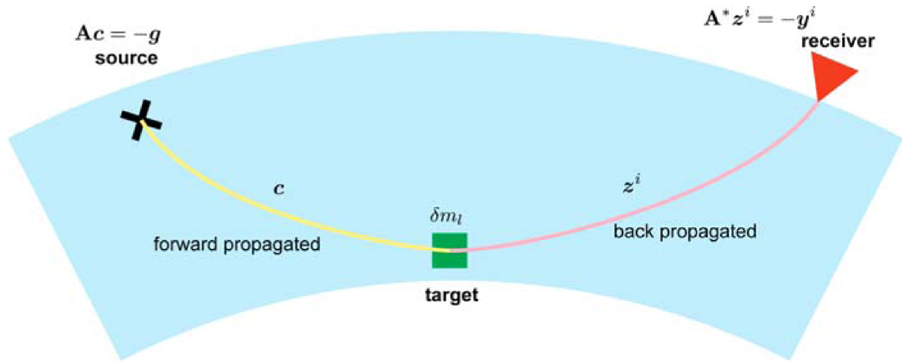
Click Here for Full Article

JOURNAL OF GEOPHYSICAL RESEARCH, VOL. 115, B01305, doi:10.1029/2009JB006503, 2010

**Waveform inversion for localized seismic structure and an application to D″ structure beneath the Pacific**

Kenji Kawai[1,2] and Robert J. Geller[3]

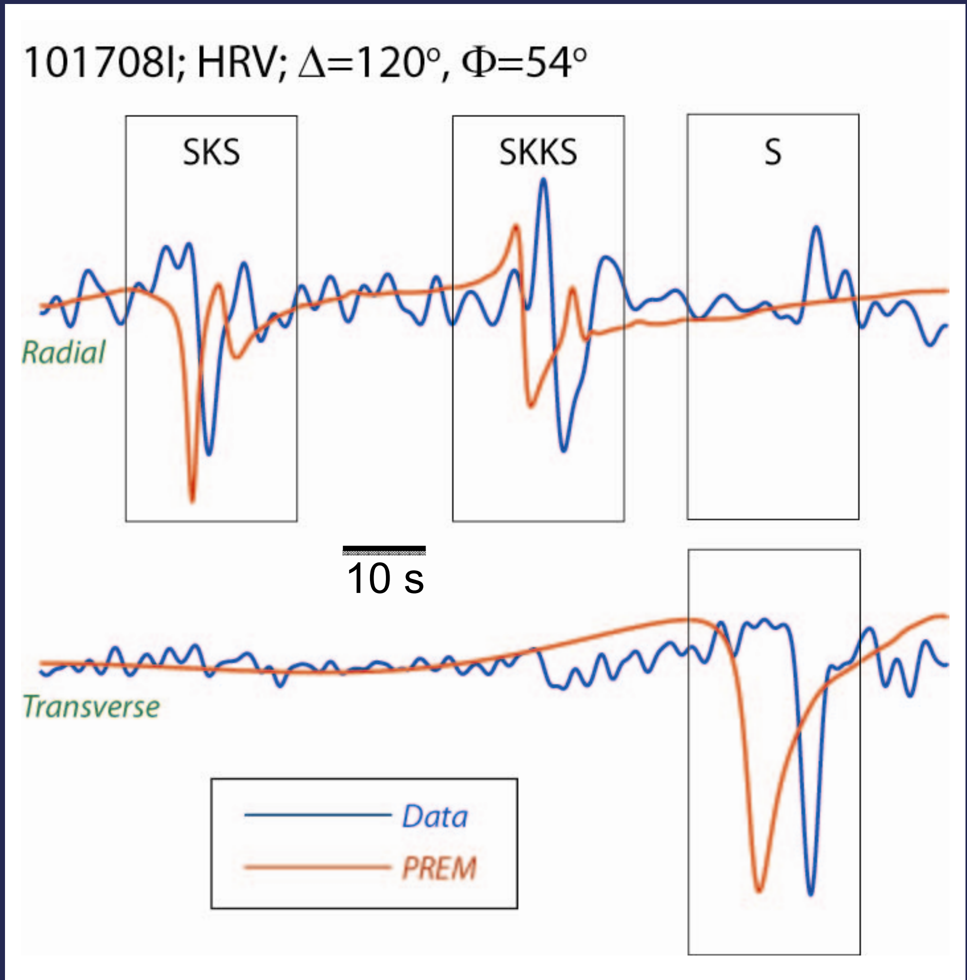
Received 1 April 2009; revised 22 September 2009; accepted 16 October 2009; published 29 January 2010.




## Kawai and Geller (2010)

- DSM synthetics
- Waveform inversion following Geller and Hara (2003)
- 1D
- SH full waveform T = 8-200 s

# Observations I

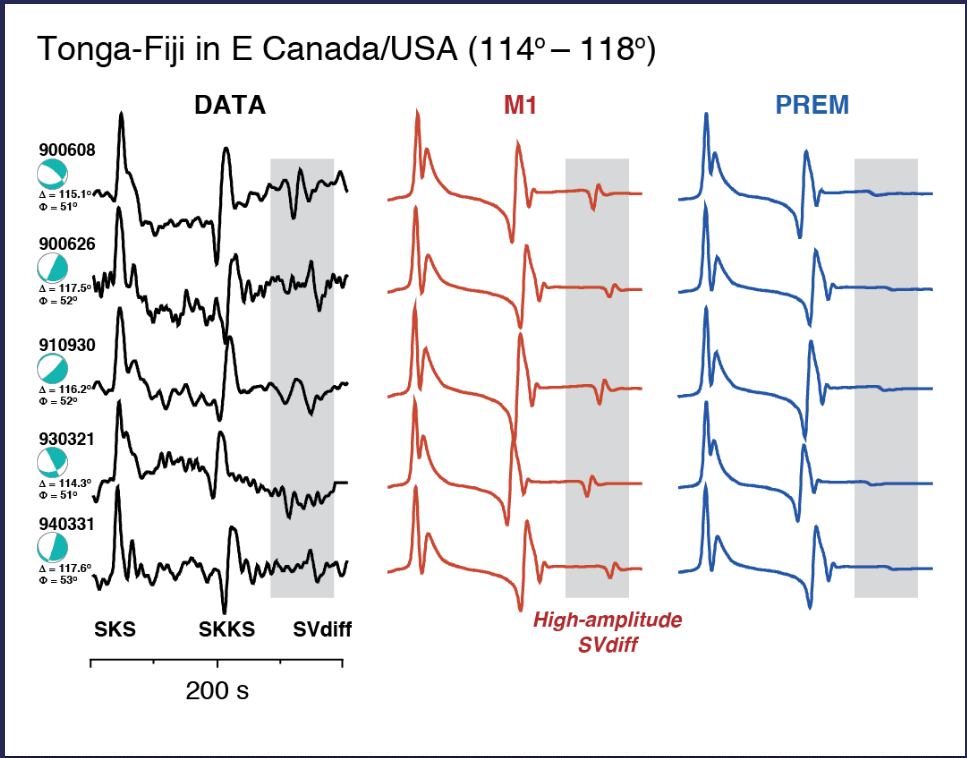



Shear waves from Tonga to North America (not used in the modeling)

- late SKS, SKKS, and S
- high-amplitude SV
- sharp SH

Vinnik LP, Farra V, Romanowicz B, Observational evidence for diffracted SV in the shadow of the earth's core, *Geophys. Res. Lett.*, **16**, 519−522, 1989.

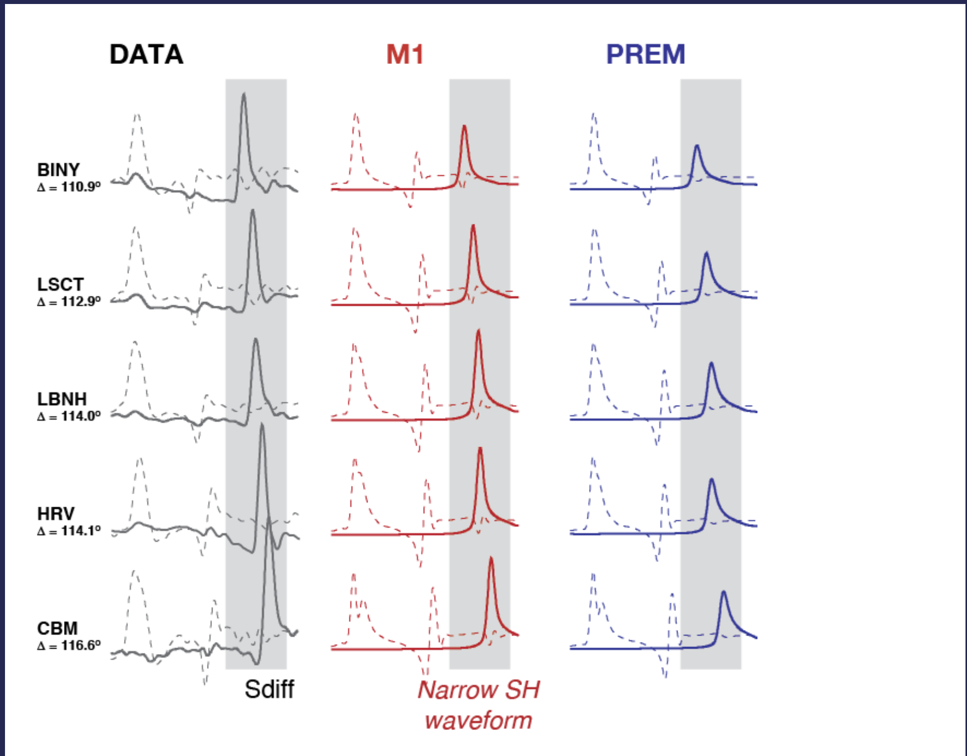
# Observations II




Shear waves from Tonga to North America

- late SKS, SKKS, and S
- high-amplitude SV
- sharp SH

# Observations III



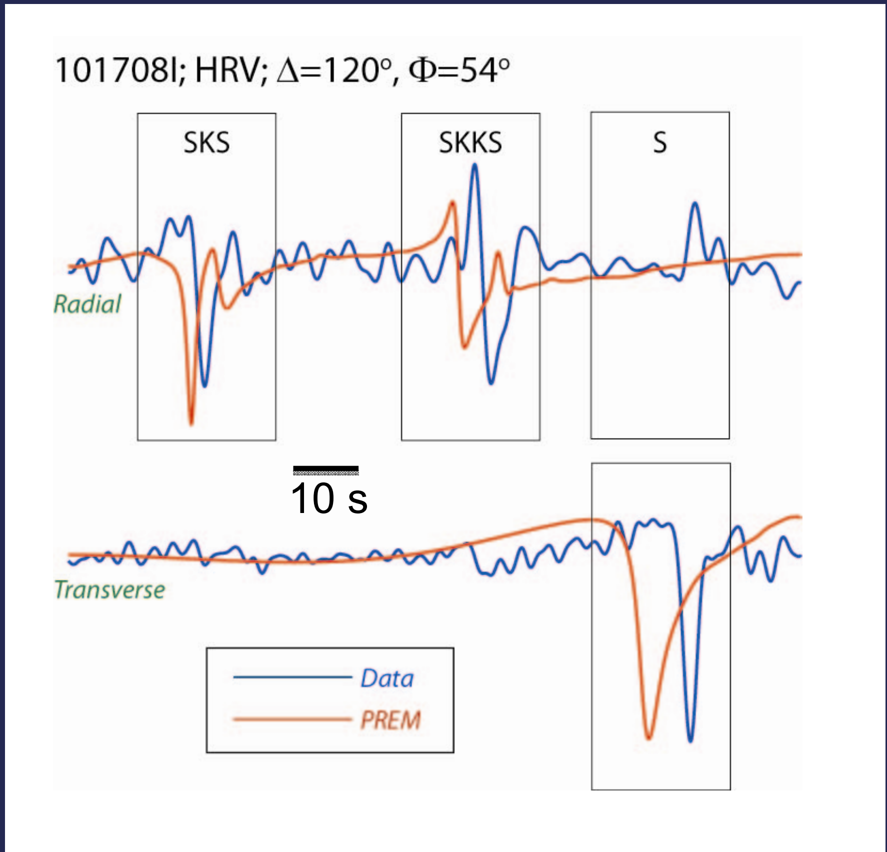

Shear waves from Tonga to North America

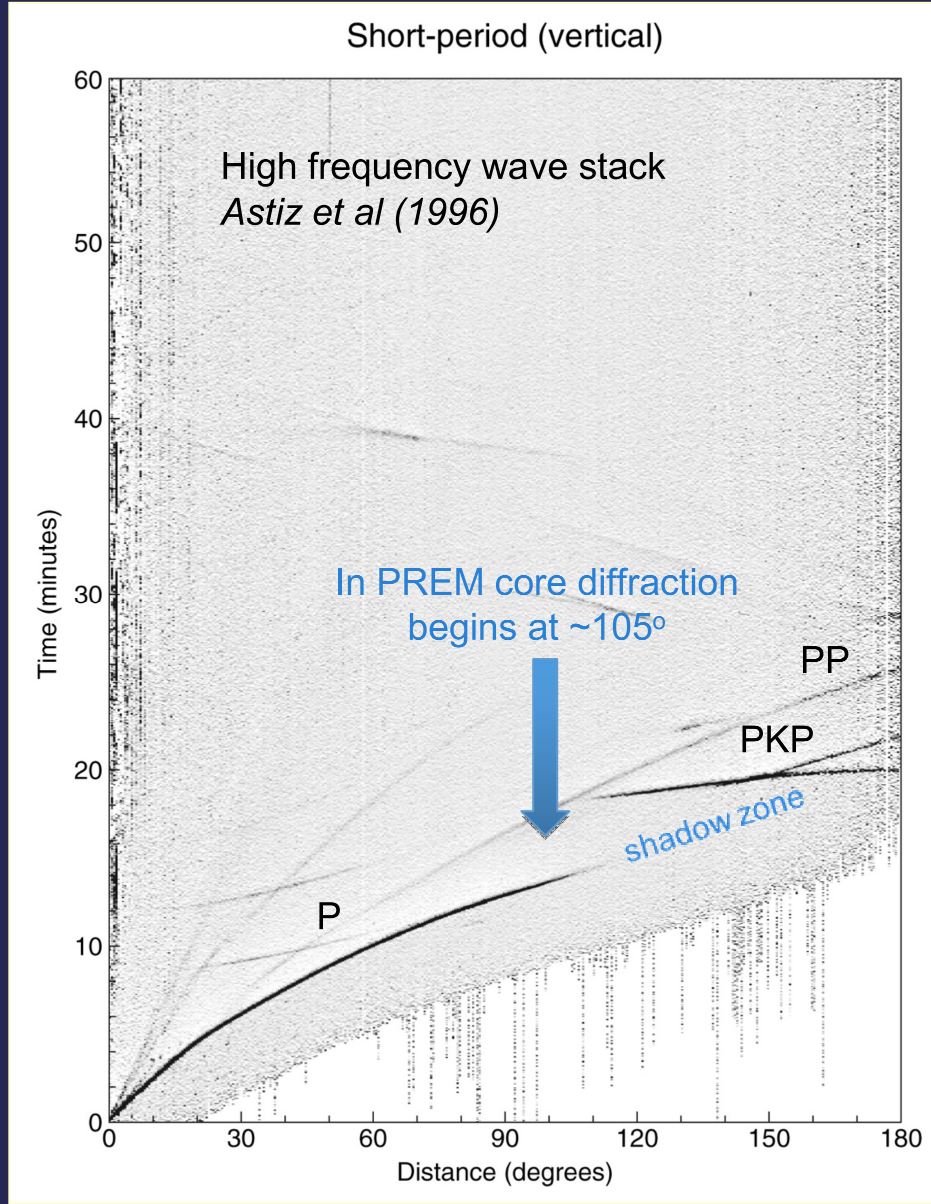
- late SKS, SKKS, and S
- high-amplitude SV
- sharp SH

# Interpretation I

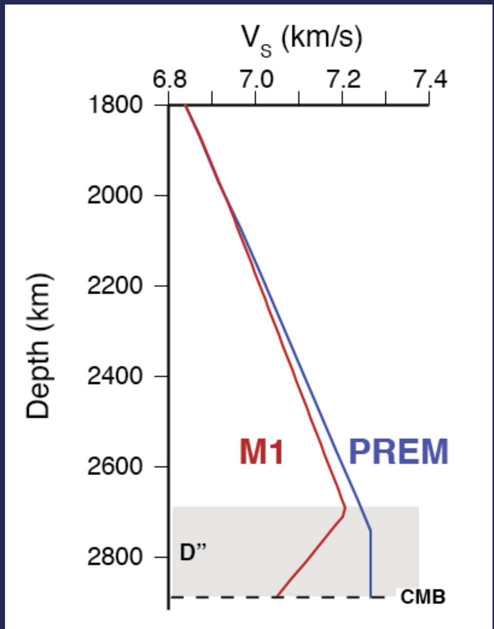
Retarded onset of core diffraction:

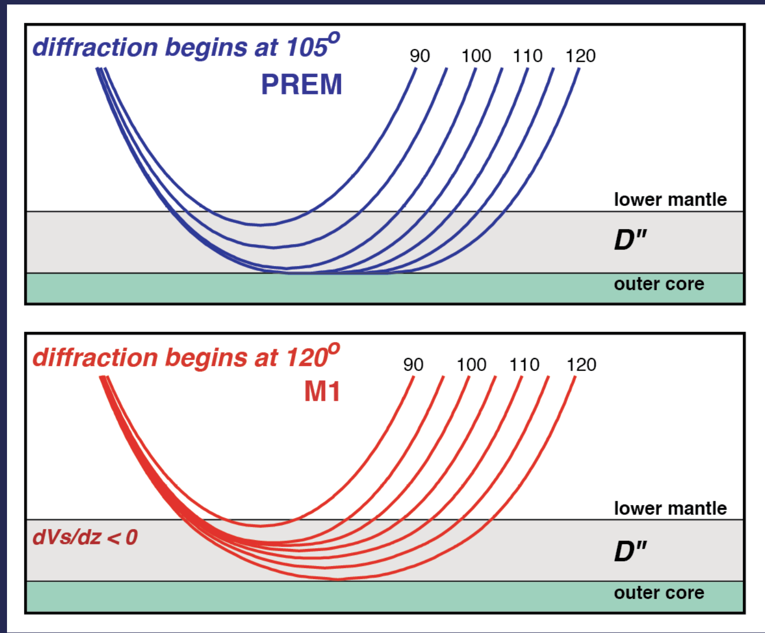
1. Onset of wave diffraction at $\Delta=120^{o}$ ($15^{o}$ later than expected)
2. delayed S wave propagation
3. perturbed S wave paths (wrt PREM)



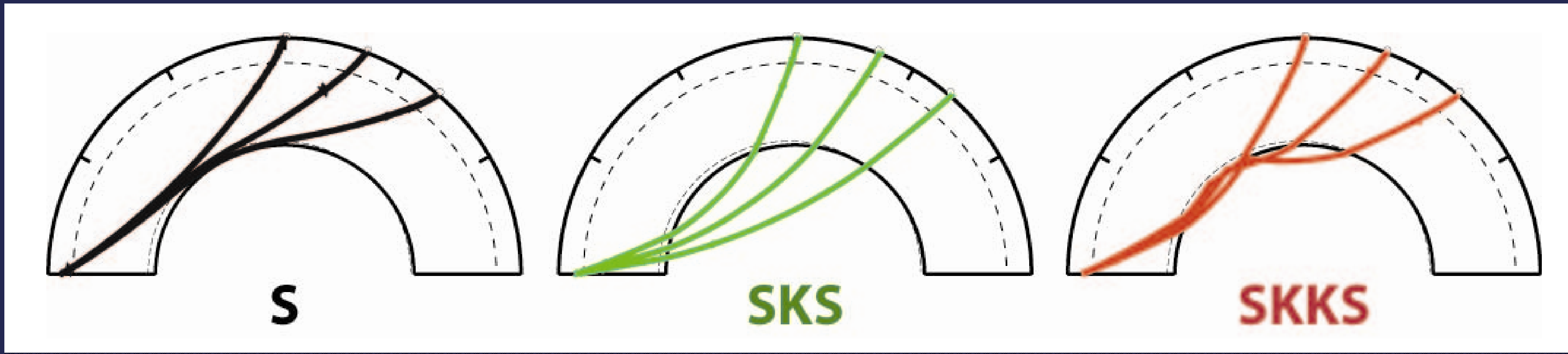
# Interpretation II



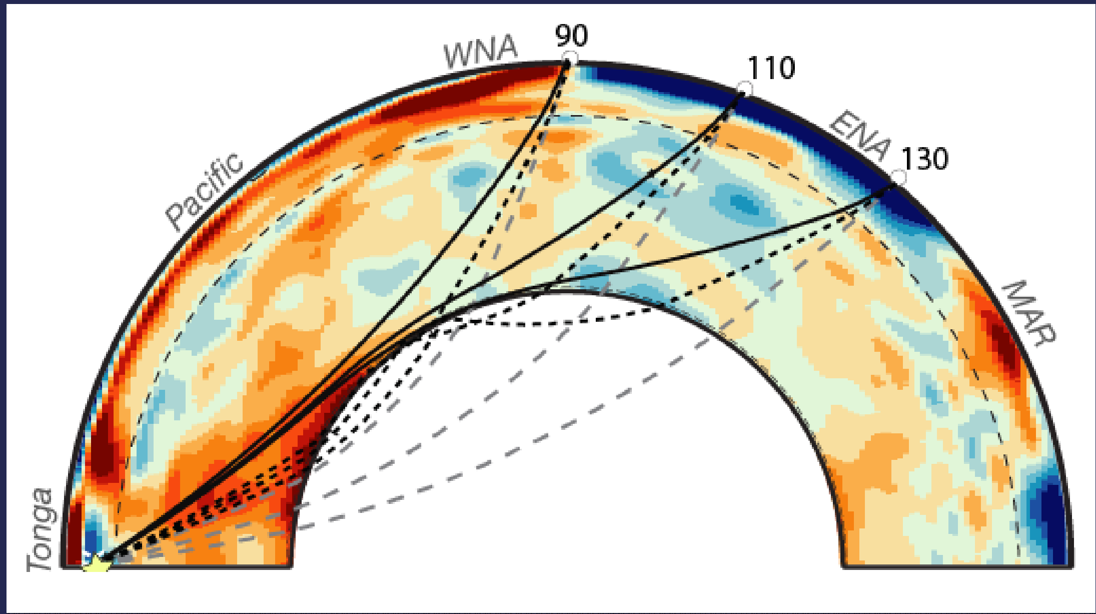




Ritsema et al., 1997

# Ray paths

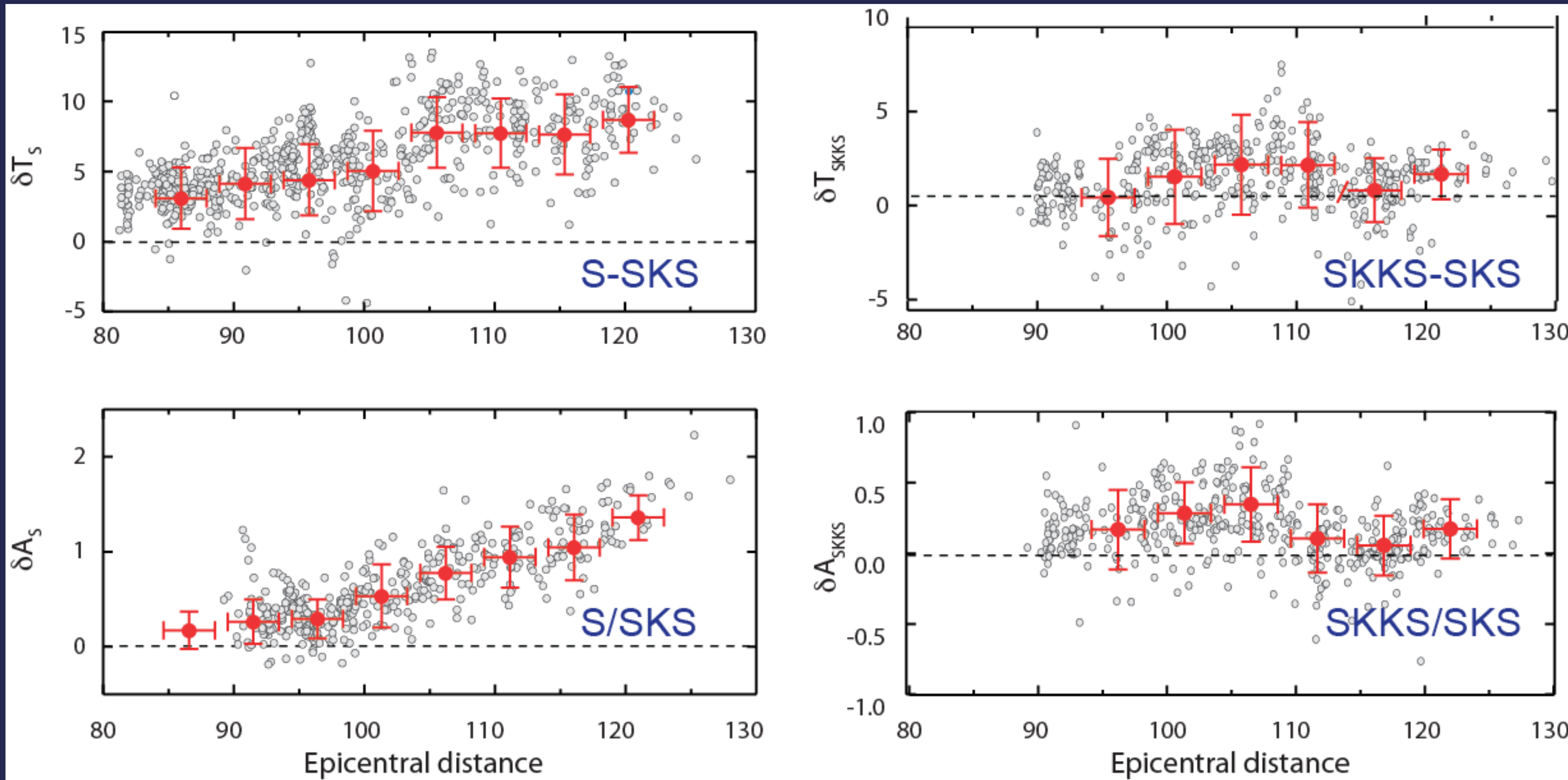


# Ray paths superposed on tomography



# Observations IV

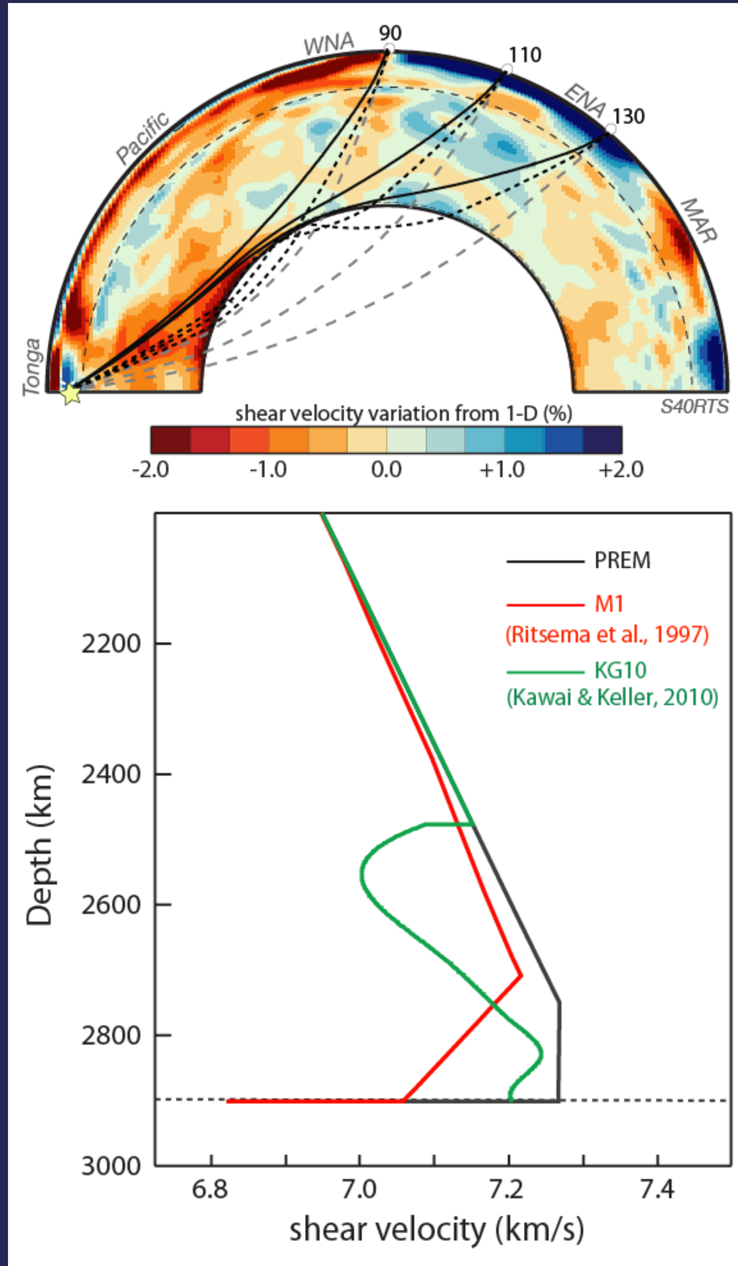
## Deep earthquakes in Tonga, stations in North America




1. High SV amplitudes, narrow SH waveforms
2. Late S-SKS (growing with distance)
3. Late SKKS-SKS (constant with distance)

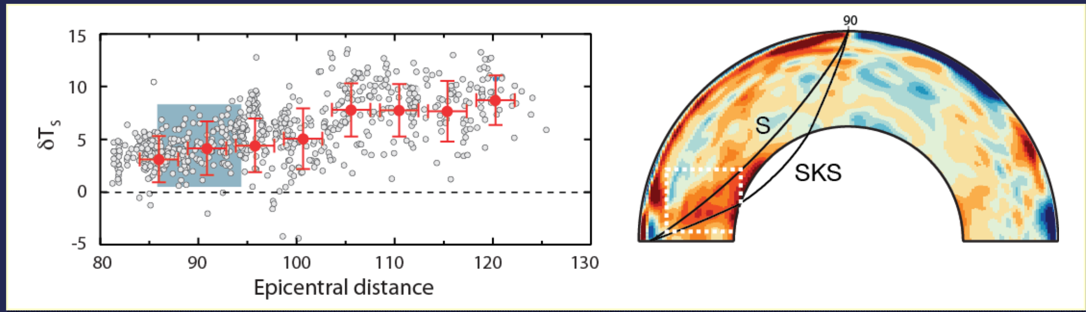
# Hypothesis

Low-resolution (but 3D) and high-resolution (but 1D) images of the Pacific mantle project the "big red blob" with different scales and artifacts.



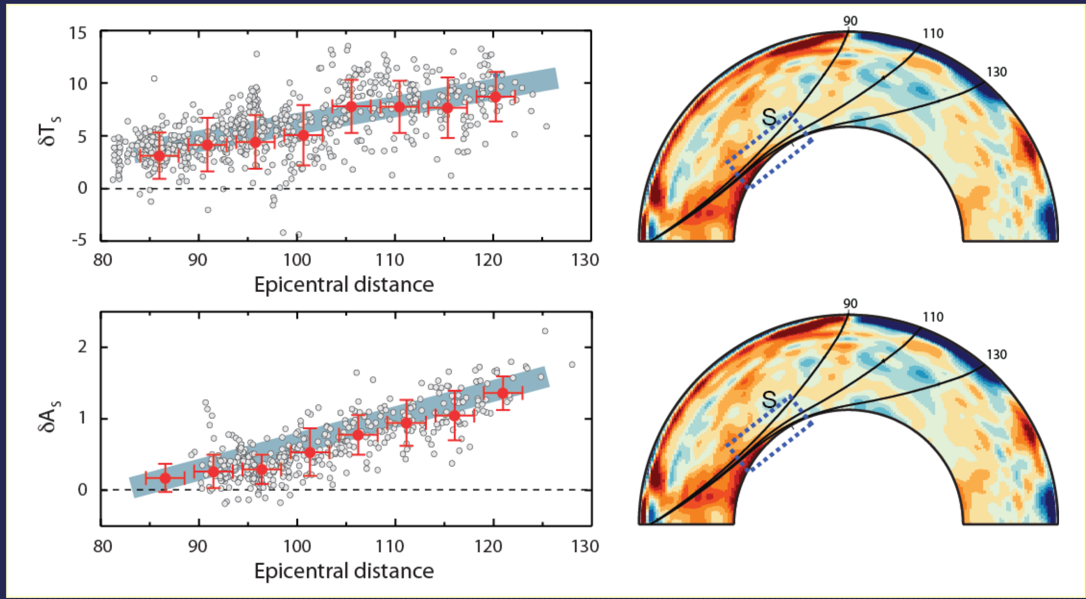
# Observations

## S-SKS times



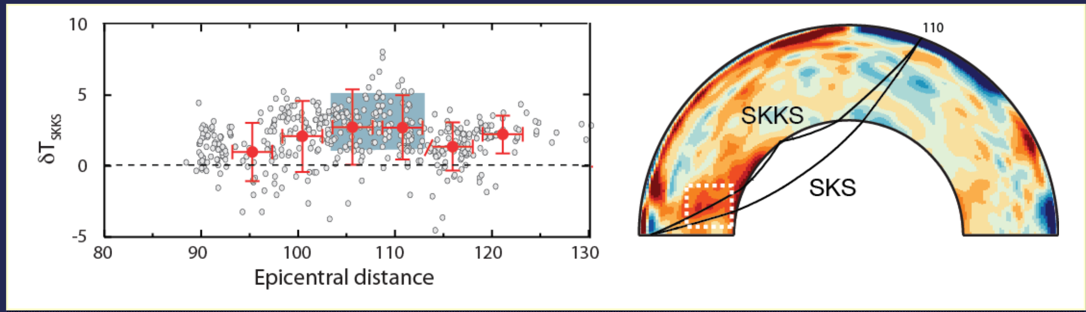
# Observations

## S-SKS times and S/SKS amplitudes

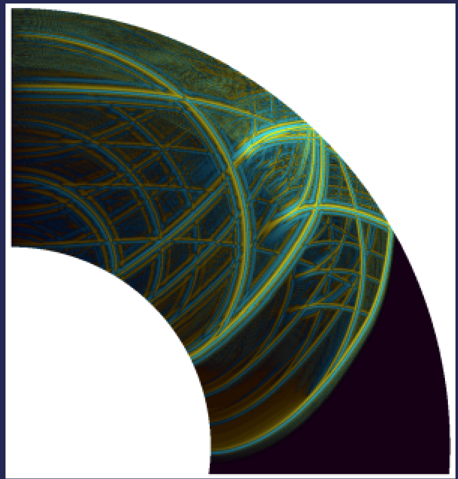


# Observations

## SKKS-SKS times



# Calculation of synthetics



SHaxi/PSVaxi

3D waveform simulations (T > 4 s) in axi-symmetric models

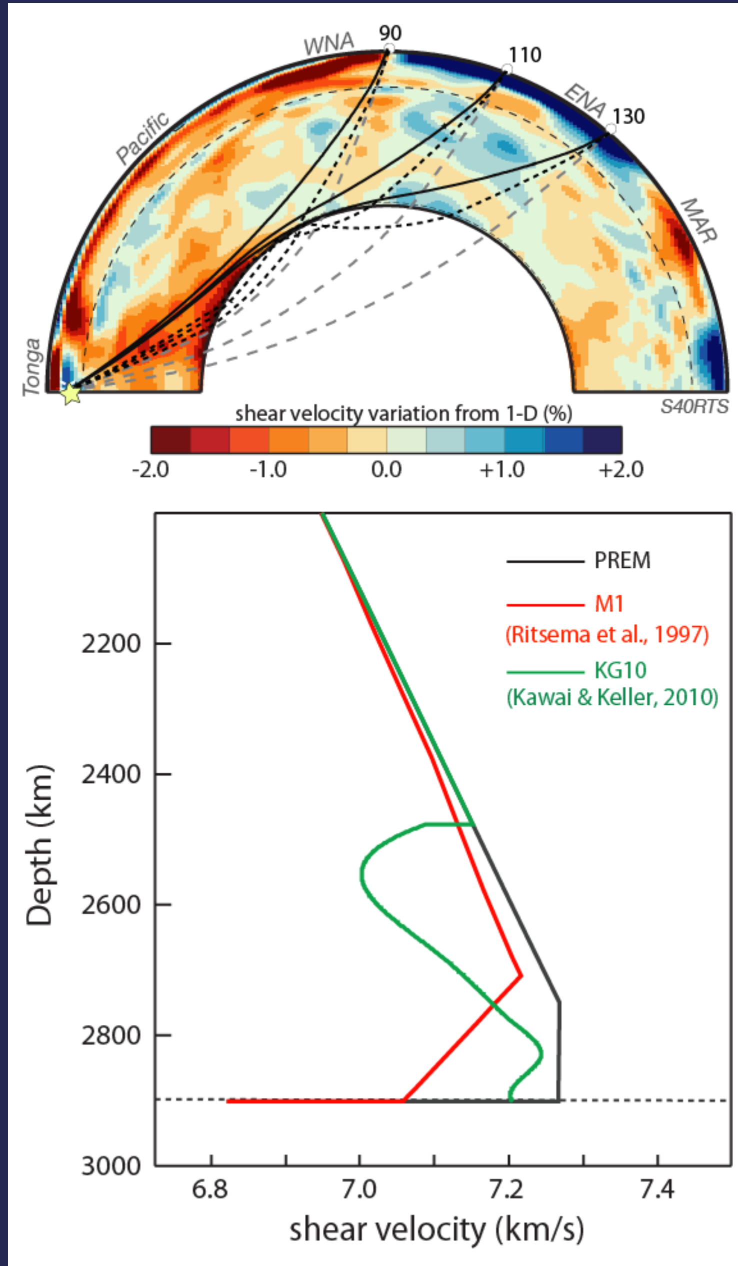
"Full" waveform analysis

travel time *and* amplitude

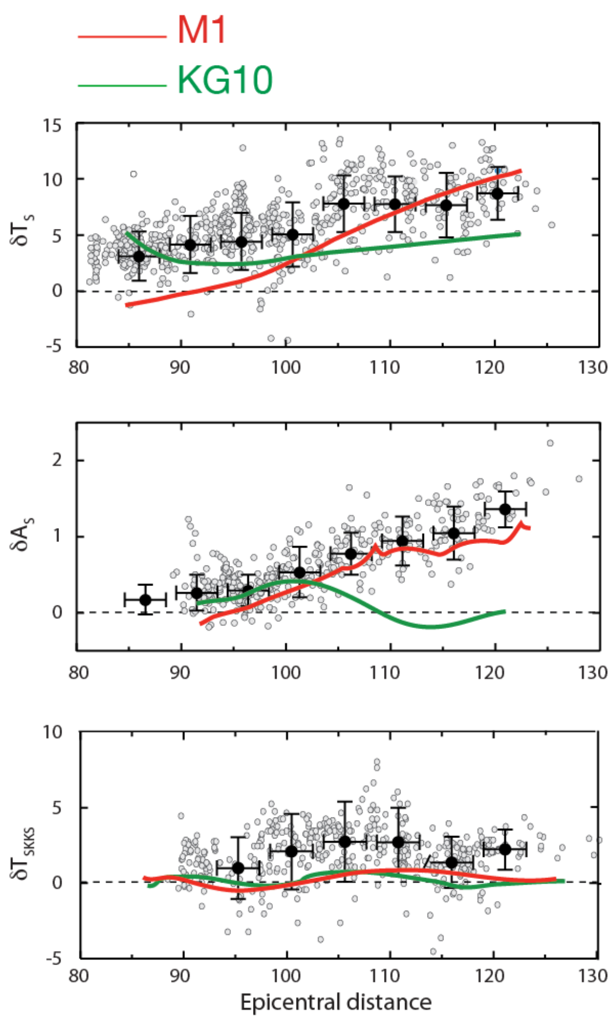
Jahnke G, Thorne MS, Cochard A, Igel H, Global SH-wave propagation using a parallel axi-symmetric spherical finite-difference scheme: application to whole mantle scattering, *Geophys. J. Int.*, **173**, 815−826, 2008.

# Hypothesis

Low-resolution (but 3D) and high-resolution (but 1D) images of the Pacific mantle project the ”big red blob” with different scales and artifacts.



# Modeling – 1D




S-SKS at short distance: M1 ✗ KG10 ✓
(shear velocity reduction well above the CMB)

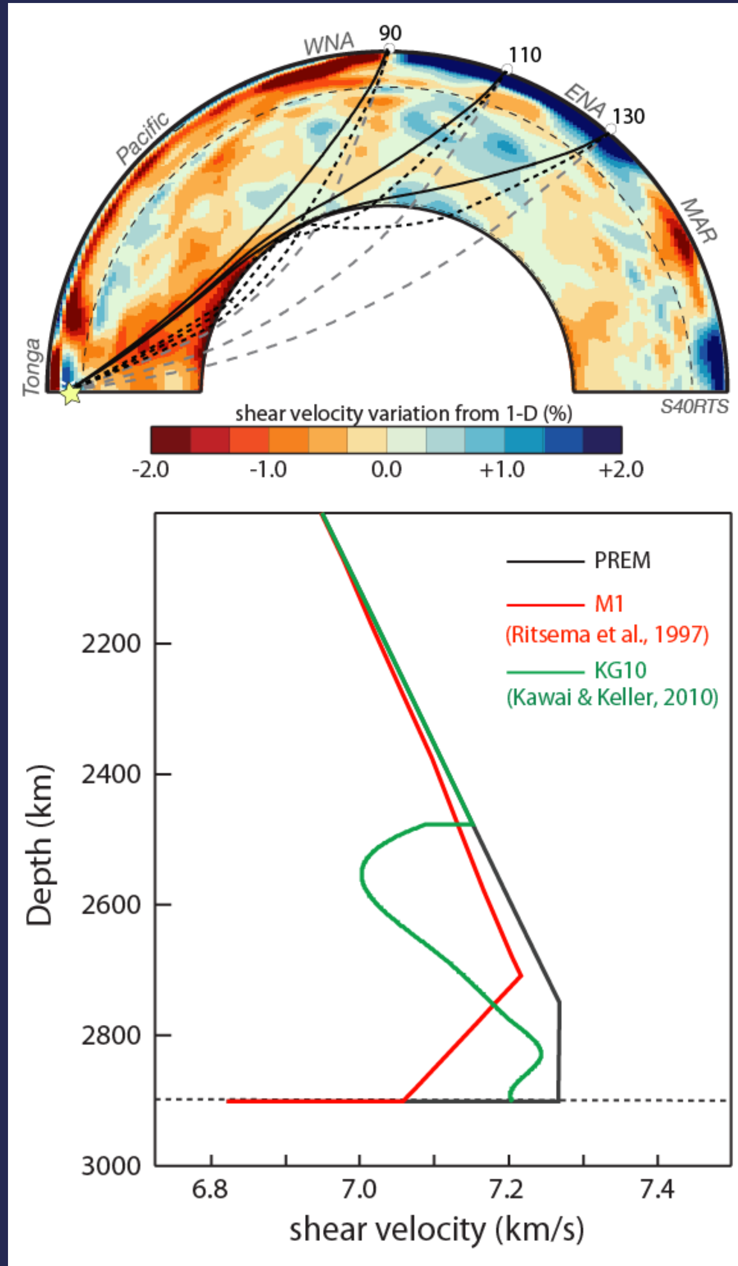
S-SKS at long distance: M1 ✓ KG10 ✗
(shear velocity reduction in D")

S/SKS: M1 ✓ KG10 ✗
(negative shear velocity gradient in D")

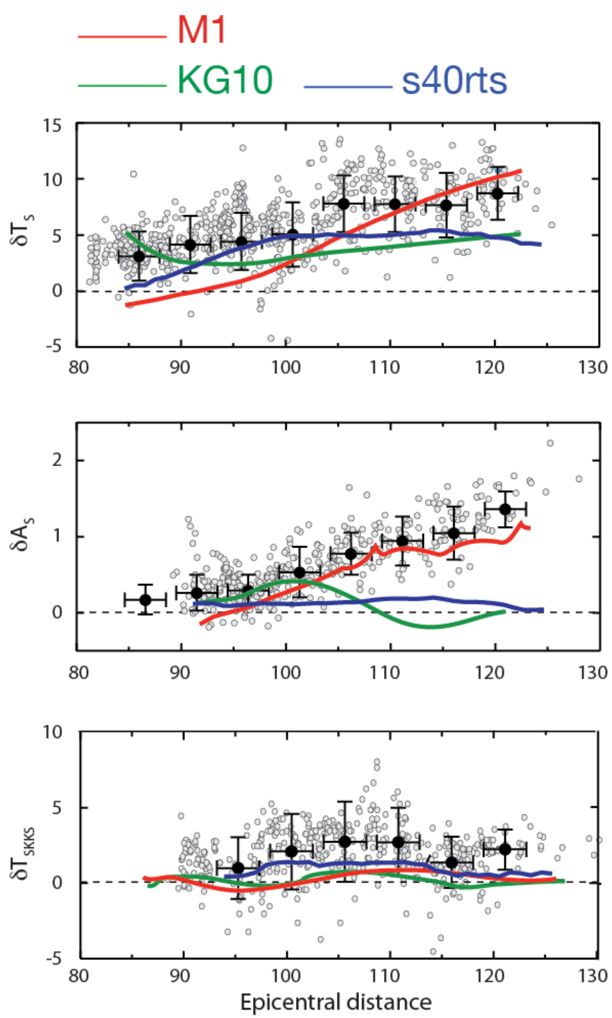
SKKS-SKS: M1 ✗ KG10 ✗
(asymmetry in velocity heterogeneity)

# Hypothesis

Low-resolution (but 3D) and high-resolution (but 1D) images of the Pacific mantle project the "big red blob" with different scales and artifacts.



# Modeling – 3D



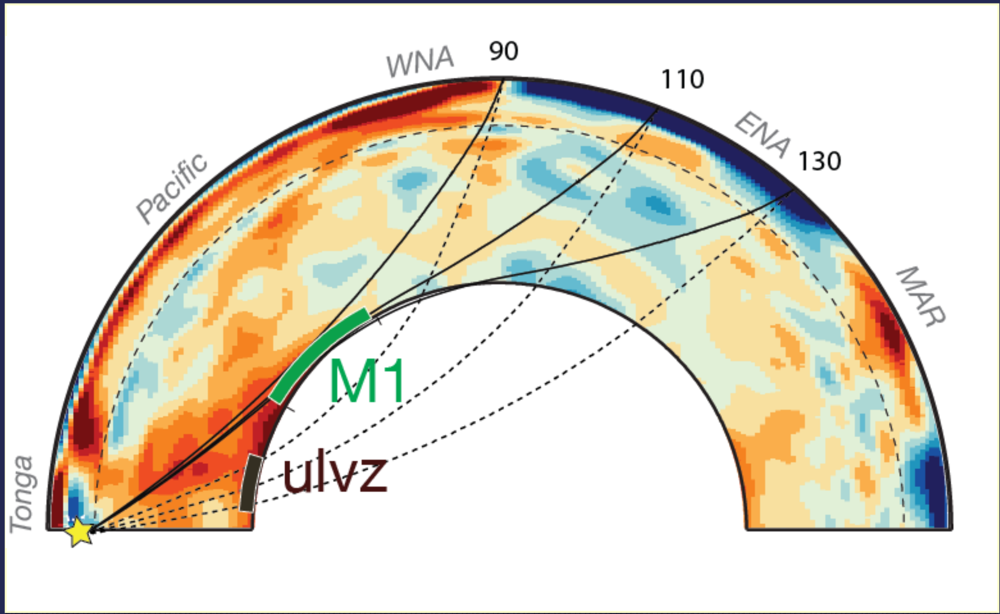

S-SKS at short distance: S40rts ✓✕
(lateral gradient at the LLSVP not sufficiently strong)

S-SKS at long distance: s40rts ✕

S/SKS: s40rts ✕
(missing negative shear velocity gradient in D")

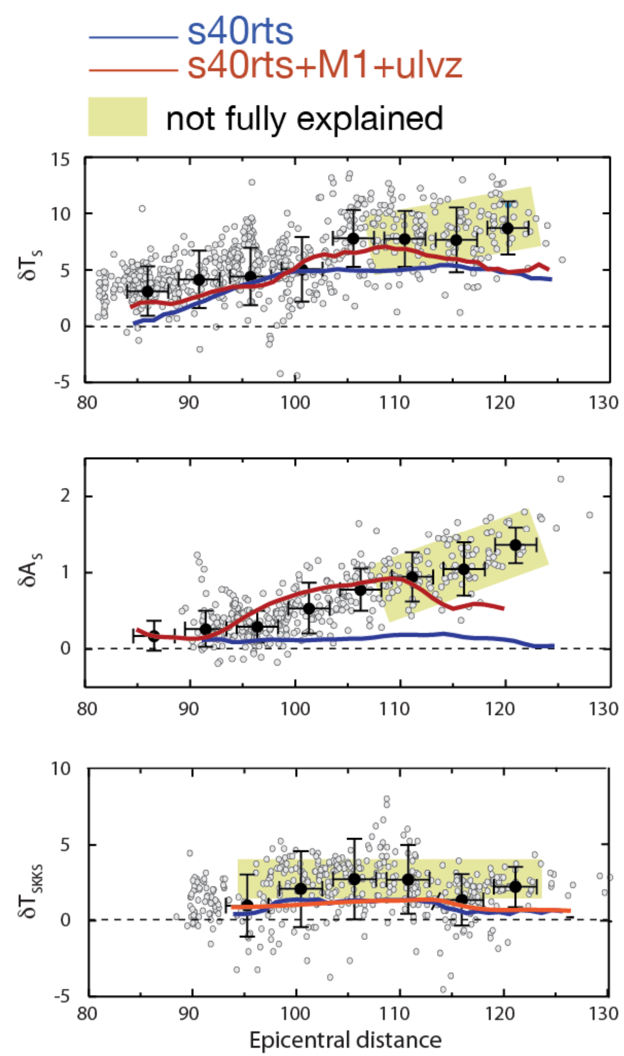
SKKS-SKS: s40rts ✓✕
(lateral gradient at the LLSVP not sufficiently strong)

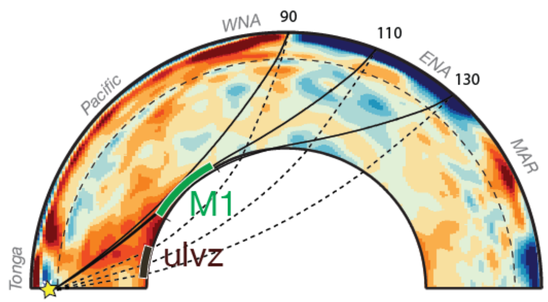
# A hybrid model: tomography + 1D profiles




- a negative gradient (“M1”) to explain S-SKS and S/SKS at distances > 100$^{o}$
- a ULVZ (“ulvz”) to explain SKKS/SKS (Zhang et al., 2009)

# Modeling – hybrid




- ULVZ at SKS core-entry point
- negative Vs gradient in D" at northeastern end of LLSVP

*A better fit can be achieved by*

•a negative gradient ("M1") to explain S-SKS and S/SKS at distances > 100°

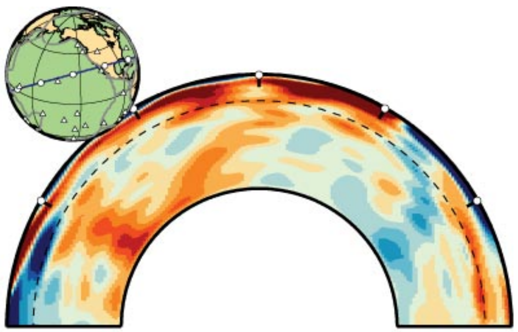
•a ULVZ ("ulvz") to explain SKKS/SKS (Zhang et al., 2009)

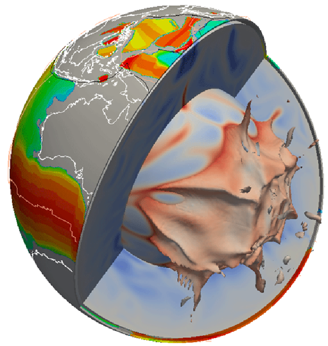
*Further improvement can be achieved by*

•extending the "M1" region further northeast

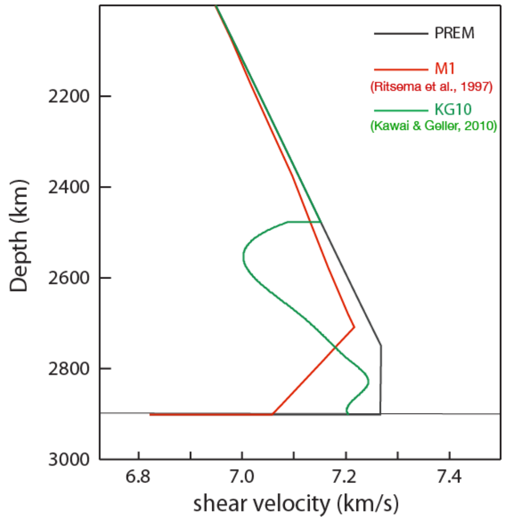
•having a sharper LLSVP

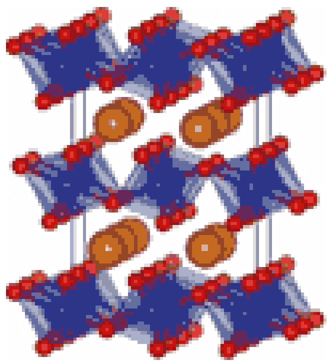
# Final remarks (… interpretations)





M. Gurnis (www)



S. Matar (www)

Large-scale, mantle-wide seismic velocity heterogeneity

- tomography does not resolve “fine scale layering”
- Strong gradients in D” are key in understanding the thermal and physical layering of the TBL

Fine-scale layering of D”

- Asymmetric heterogeneity cannot be modeled in 1D.
- Regional data is influenced by global structure
- artificial swings in the profile can be misinterpreted as pv-ppv transitions

Model depends on

•chosen data (S only? amplitudes?)

•parameterization (1D?, 3D?)

# Final remarks (… the pool quiz)

Het hummeltjeshonk, Emmen, 1970

First publication:

Ritsema J, Lay T, Rapid source mechanism determination of large ($M_w$>5) earthquakes in the western United States, Geophys. Res. Lett., 20, 1611–1614, 1993.

20 years ago this month!!

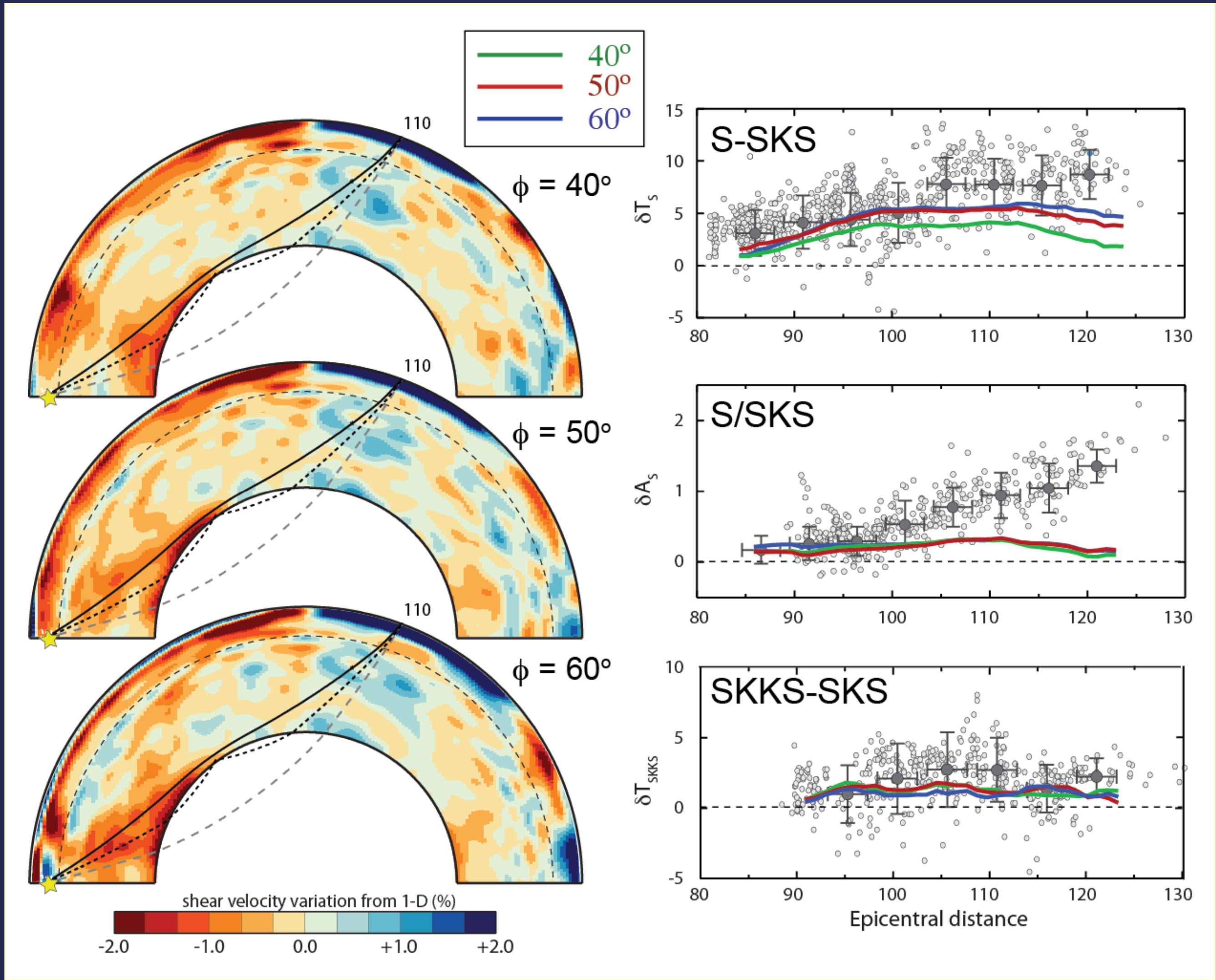
# Final remarks (… interpretations)


L. Boschi (www)

Somehow we have to model the Earth on all scales

- “multi-scale” parameterization
- it is dangerous to model/interpret seismic data with only one scale in mind
- Include anomalous signals, even if they are tiny and complex

# Off-azimuth effects



# Modeling – sensitivities